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PRECISE CALIBRATION OF COHERENT AND NON-COHERENT

WEATHER RADARS BY MEANS OF A RADAR TRANSPONDER

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1. INTRODUCTION

Over the years, a number of weather radar calibration techniques have been developed. In general, these techniques can be grouped into two approaches: (1.) Those which measure the effect of individual components in the transmitter and receiver chain; and (2.), those which provide a lumped system calibration constant without resort to the identification of component contributions. Calibrations utilizing suspended standard radar targets such as metal spheres and techniques involving comparisons of radar derived reflectivities with those determined from particle measurements (Joss et al., 1968) are two lumped techniques which are oftentimes selected over discrete component calibrations because the lumped measurements can be performed either during or very near the time of the radar observations. However, none of the techniques employed thus far can provide these calibrations on a systematic basis throughout the period of radar observations. As greater and greater emphasis is placed upon quantitative measurements with large scale data processing equipments, the need for more frequent radar calibrations becomes more and more important.

This paper describes a versatile coded radar transponder technique which is intermediate between the lumped and discrete component approaches in that this transponder provides for separate calibrations of the transmitting and receiving systems. One very nice feature of this approach is that once the transponder is sited, adjusted, and calibrated, radar transmitter and receiver calibration data can be obtained at the radar as often as desired. Moreover, the transponder also provides a single frequency calibration signal which is useful for monitoring Doppler receiving and processing equipments.

2. CONCEPT OF OPERATION

The concept of operation of this coded transponder can probably best be understood by considering the transmitter and receiver measurements in separate steps. For example, let us assume that we have a means of acquiring a signal which is proportional to the RF signal transmitted by the radar. In practice, this signal can be acquired vice a directional coupler located in the radar transmit/receive waveguide line or via a standard gain horn located in the far field of the radar antenna. Let us now further assume that we have a means of taking the detected envelope of this transmitted RF pulse, looking at fine scale increments of say 1 dB both

above and below the peak of the envelope, and deciding if the envelope does or does not cross each particular power threshold. For the purpose of this example, if there are a total of 16 levels and the amplitude of the envelope falls midway between the thirteenth and fourteenth level, then the radar transmitted power will only have to change by slightly more than ± 0.5 dB and the envelope will fall into the level ± 1 from thirteen. This approach can thus provide a means of monitoring relative changes of 1 dB in the radar peak transmitted power ΔP_t, over an interval of +3 to -13 dB around the average value $\overline{P}_t$ at the time the measurements begin. Since there are well known discrete type calibration techniques for determining the average peak transmitted power, P_t, at the horn of the radar antenna from measurements taken either in the radar receiver/transmitter waveguide line or in the far-field of the radar antenna pattern, a monitoring of the peak transmitted power, P_t, can thus be achieved by first measuring $\overline{P}_t$ with a test set and then measuring ΔP_t with the transponder located at the $\overline{P}_t$ measurement point. Moreover, these measurements of ΔP_t can be continuously available on a pulse to pulse basis whenever the transmitter RF signal is sensed at the input to the transponder.

Thus far in the discussion, there has not been evidence of a transponder type response; however, if the measurements of ΔP_t are to be useful, they must be available at the radar in a manner suitable for automatic data processing techniques. These ΔP_t measurements must be injected into the radar receiving system and, moreover, the receiving system itself must be calibrated. A means of achieving both of these objectives can be developed by recalling that the ΔP_t measurements are digital (yes or no) indications of the presence of the RF envelope at each of $16 = 2^4$ different equally spaced power intervals. The entire ΔP_t measurement can therefore be encoded as a 4 bit digital word, a word which can be delayed and repeated to any degree desired. Thus, if a fifth bit is added to denote start of data, the 5 bit code corresponds to a group of from 1 to 5 pulses which can be used to gate a stable but not necessarily coherent low power RF oscillator for transmission or injection back to the radar system for decoding by the data processing equipment. Moreover, if the amplitude of this pulse code is constant and known, then the amplitude of the pulses becomes a calibration signal for the entire radar receiving equipment. But these pulses can be a calibration signal only if they are devoid of outside influences such as receiver recovery time effects and ground clutter echoes if the transponder is at the radar and ground clutter

and precipitation echoes if the transponder is in the antenna far field. To minimize these influences, the start of data pulse is delayed in radar range time to place it out of the range of ground clutter and at a distant range where precipitation is seldom detected. Moreover, in order to lessen the chances of precipitation influencing these measurements, the 5 bit pulse code is repeated 3 times so that one or two sets of calibration pulses are clear of these targets. At very high pulse repetition frequencies (PRF's) these precautions may not be sufficient; however, they certainly should be adequate for the large unambiguous ranges corresponding to the lower PRF's.

There is another type of transponder action which is useful with a Doppler radar provided that the transponder is located in the far field of the radar antenna. For example, it is possible to utilize the radar transmitted pulse received at the transponder by first passing the signal through a digital RF phase shifter, which changes the phase of the RF pulse in discrete steps at a constant rate, and then re-radiating this phase back toward the radar. Since a rate of change of phase is precisely the effect measured by a Doppler radar, the power density spectrum, for the range of the transponder, is essentially a single line at a frequency equal to constant rate at which the phase is changed. Such a Doppler shift is a handy reference standard for monitoring the entire radar transmitter/receiver/data processor chain of equipment. Moreover, since Doppler data processing equipments such as the pulse pair processor (Novick and Glover, 1975) provide measurements expressed as a fraction of the radar PRF, the known frequency spectrum provides a means of automatically measuring the PRF with these processors and scaling the measurements according to the PRF used.

3. TRANSPONDER BLOCK DIAGRAM

A coded transponder capable of providing the transmitter, receiver, and single frequency Doppler calibration signals described in Section 2 is shown in Figure 1. Upon receipt of a transmitted pulse from the radar, the internal timing of the transponder begins, and for approximately the first 10 microseconds, the device operates in the coherent mode. It is during this time that the received pulse is phase-shifted and re-radiated without delay. The received RF pulse in the 3 dB part of the directional coupler is channeled to a RF detector which produces a video output representative of the received pulse power. This video output pulse is sent to a power divider which splits the power evenly into 17 parts and applies the resultant 17 equal amplitude pulses to a set of 17 voltage comparators, of which one is the start of time output and 16 are power comparison outputs. Upon sensing the receipt of a pulse, the timing control supplies a clock pulse to the attenuator control and the digital attenuator, a digitally controlled switch whose normal position is open, is commanded to its minimum loss state. Thus, the received pulse in the main line of the directional coupler is passed through the RF switch, whose normal position is toward the input RF line, and on to the phase shifter. Since the phase shifter is controlled to scan slowly in discrete steps in phase between 0 and 2π at a constant but adjustable rate, the received RF pulse is shifted by a fixed increment

of phase, passed by the attenuator, scaled by the amplifier, and then re-radiated at the horn.

After approximately 10 microseconds, the transponder shifts to the incoherent mode; the RF oscillator is switched to the phase shifter and the digital attenuator is switched open to await commands to operate the required pulse train. During the time the timing unit is sensing the start of the timing sequence, it is also sensing the 16 power comparison outputs and counting time from an internal 4 M HZ crystal controlled digital clock. Each comparator has an adjustment to accurately calibrate ($\pm \frac{1}{2}$ dB) the measurement of the received power at a given level. These comparators are individually adjusted to sense the presence of the radar's detected pulse at each of 16 levels spaced 1 dB apart and to place 12 of these 16 levels below the reference (measured) value of the pulse power. The timing unit encodes these measurements into a 5 pulse response which is repeated three times after receipt of the transmitted pulse. The first pulse indicates that a radar pulse has been received and the remaining pulses form a 4 bit digital code which relates the strength of the transmitted pulse to that of the reference. The coding of the 5 pulses is shown in Table 1.

Table 1

Received Signal with respect to Reference (dB $\pm \frac{1}{2}$ dB)	Pulse 2	Pulse 3	Pulse 4	Pulse 5
+ 3	1	1	1	1
+ 2	1	1	1	0
+ 1	1	1	0	1
0	1	1	0	0
- 1	1	0	1	1
- 2	1	0	1	0
- 3	1	0	0	1
- 4	1	0	0	0
- 5	0	1	1	1
- 6	0	1	1	0
- 7	0	1	0	1
- 8	0	1	0	0
- 9	0	0	1	1
-10	0	0	1	0
-11	0	0	0	1
-12 or less	0	0	0	0

Each of the 3 sets of 5 pulses is independently adjustable in time, but the 5 pulses are fixed in time with respect to each other. Output signals from the timing unit are used to enable the digital attenuator to produce the proper code, with respect to the received power level, that is re-transmitted to the radar during the incoherent mode of operation.

In order for the coded pulse train to serve as a calibration signal for the radar receiver as well as the transmitter, the amplitude of the pulses must be constant and known. Both the power output from the RF oscillator and the gain of the RF amplifier must be constant. The RF oscillator need not be phase locked to the radar transmitter, for there is no need for coherency in the power channel; however, the oscillator must be of sufficient frequency stability to stay in the center of the radar receiver passband for long periods of time. If care is exercised in the selection of the oscillator, these

problems should not degrade the performance of the device. For example, at 10 cm wavelength, the typical frequency stability of a GUNN oscillator is approximately 140 k Hz and its power output is constant to within ± 0.2 dB over a one month period of time.

4. DISCUSSION

This transponder technique offers considerable promise in the calibration of both Doppler and non-Doppler radars. The device can be built for any single frequency microwave radar, and moreover, it can be adapted for use at the radar as a test set to provide a continuous power calibration of the transmitting and receiving systems if the effects of external influences such as water or ice on the radar radome can safely be ignored. Operation of the device at the radar overcomes the chief disadvantage of a transponder: the operation of equipment remote from the radar. On the other hand, operation of the transponder in the far field of the radar antenna does provide a means of monitoring the complete system losses including weather effects on radomes, and also provides a sufficient delay in radar range for the Doppler shifted calibration signal to be effective. But probably the nicest feature of the device is that it encodes the measurements in a form which is automatically injected into the radar automatic data processing equipments. As the National and Air Weather Services move toward greater automation, this approach may provide a much needed means of standardizing their network of radars.
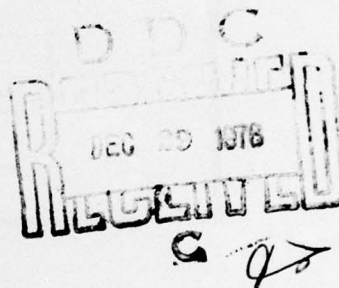
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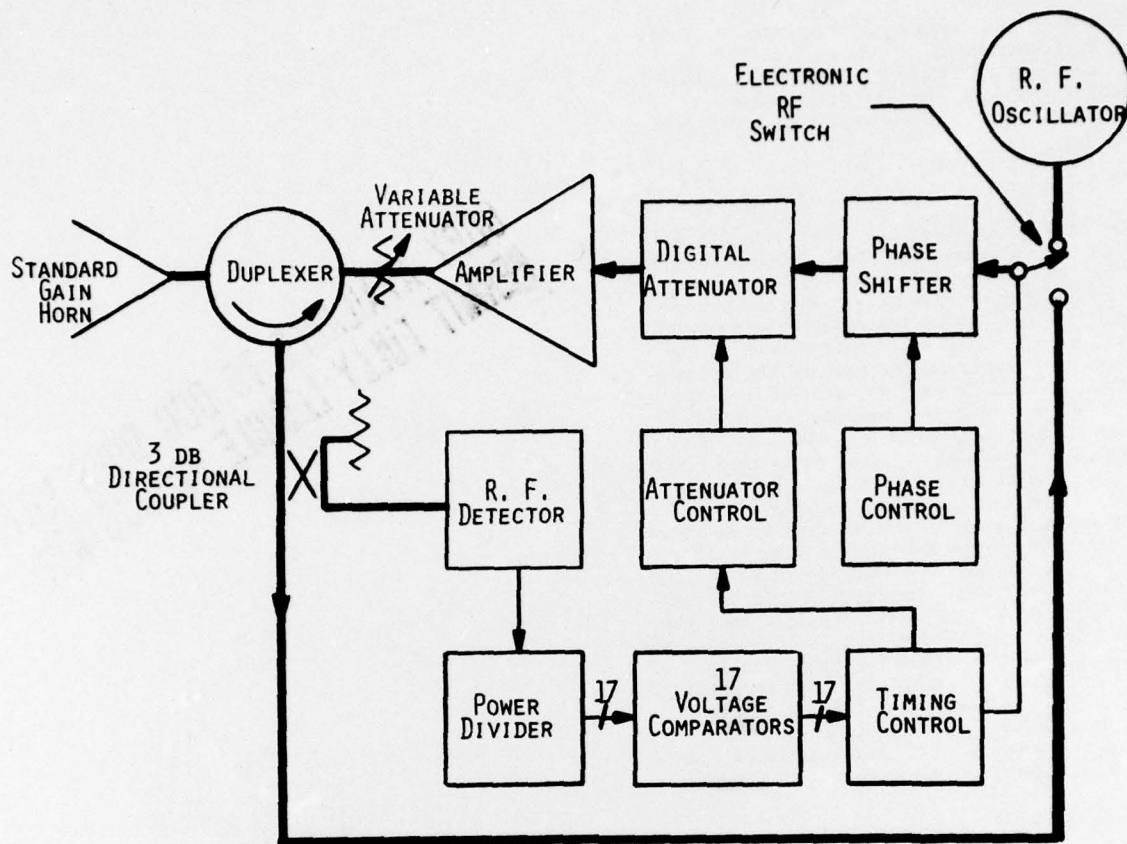
Figure 1.   The coded radar transponder.   RF signal paths are
denoted by wide lines; digital logic and control paths are
denoted by narrow lines.

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13. ABSTRACT

A generalized transponder technique for calibrating both Doppler and non-Doppler radars of arbitrary wavelength is described along with the hardware necessary to enable pulse to pulse radar system calibrations accurate to $\pm 1/2$ dB.

The transponder, which is located in the far-field of the antenna, is designed to make the calibration insensitive to the magnitude of the ground clutter region surrounding the transponder. The accuracy and ease of measurement using this approach make it useful for both research and operational applications.

Preliminary test results obtained with a 10 cm transponder and a 10 cm Doppler radar are described and compared with results obtained tracking metal spheres of known cross-section.

KEYWORDS: Radar transponder, Radar calibration, Weather radar, Radar measurements

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